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We describe a diagnostics system developed, to measure exponential gain properties and the electron beam dynamics inside the strong focusing 4-m long undulator for the VISA (Visible to Infrared SASE Amplifier) FEL. The technical challenges included working inside the small undulator gap, optimising the electron beam diagnostics in the high background environment of the spontaneous undulator radiation, multiplexing and transporting the photon beam. Initial results are discussed.

1. Introduction

The intra-undulator diagnostics system at the VISA experiment [1] has a dual purpose: (i) align and match the electron beam in the undulator; and (ii) to measure the FEL radiation properties along the length of the undulator [2]. While the second task remains the experimental objective, it is the first one that focused most of the attention of the authors during the initial stage of VISA experiment. For the proper characterisation and optimisation of the FEL process, it is necessary to measure the electron beam trajectory and envelop throughout the length of the undulator, and apply a proper correction (for instance to align the electron beam to the undulator axis with the 20 μm accuracy).

The VISA experiment utilises a strong-focusing undulator [3], with the average electron beam beta-function of about 30 cm (Table 1). Hence, proper diagnostic technique requires sampling period to be 90 cm or less. To accomplish that, the undulator vacuum chamber was equipped with 8 diagnostic ports 50 cm apart. OTR and undulator radiation probes, alignment lasers, and multiplexing optical transport are the major components of the intra-undulator diagnostic system.

2. Diagnostic Probes

One of the most challenging parts of the VISA experiment was the design and fabrication of the diagnostic probes. The purpose of the probes is both to extract an FEL light out of the undulator vacuum chamber, and to enable the electron beam imaging (Fig. 1). When the electron beam path is being intercepted by the outer surface of the probe two-sided mirror, the FEL light is being extracted and directed into the optical transport line. On the opposite side, the inner mirror directs the radiation through the periscope mirror into the imaging system, where the FEL light is being filtered out and the OTR from the mirror surface is used to generate an image of the electron beam.

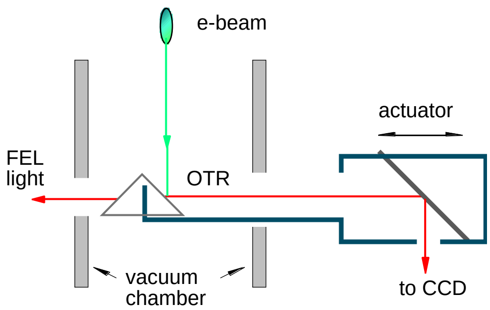

Figure 1: Intra-undulator diagnostic probes diagram.

The miniature openings inside the undulator gap (3.6 mm x 9 mm) put a very stiff limitation on the size of the probe tips. Initially, to maximise the two-sided mirror surface, we built probes with a marginal thickness of 3.3 mm. In addition to the difficulties with the probe insertion in the undulator gap, it turns out that the bellow-coupled vacuum feedthroughs used to actuate the probes tend to tilt after the pump-down, and as a result, the probe tip may not clear the opening, which is not acceptable

Table 1: Relevant parameters for VISA FEL

Nominal Beam Energy	71MeV
Charge	1nC
Undulator Period	1.8 cm
Number of Periods	220
Average $\beta-$ Function	30 cm
Radiation Wavelength	800nm

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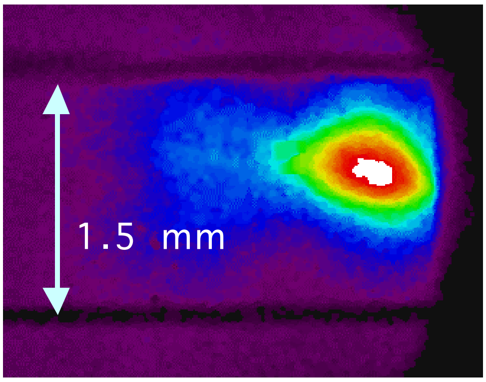

Figure 2: OTR image of the VISA beam in the middle of the undulator

for many reasons. Hence, the latest design utilises 2.3 mm thick probe tips. It is very difficult to polish laser quality mirrors of that size; therefore, the original copper mirrors were replaced with the silicon ones, polished to λ/10. The mirror polishing has been performed at LLNL, and the probe fabrication was done at SLAC and BNL.

Another important change in the diagnostic system is the use of optical transition radiation (OTR) for beam imaging, instead of the YAG crystals originally proposed. The experimental study [4] at ATF (Accelerator Test Facility) demonstrated, that the YAG crystal scintillators get saturated by the high brightness electron beam (beam of quality identical to the VISA design parameters). As a result, information about the size and shape of electron bunches, which is critical to analyse the FEL performance, can not be obtained from YAG images (Fig. 3), which consistently overestimate the beam radius. To avoid this problem we have to use OTR diagnostics, which provides correct information about the beam transverse profile. However, the OTR has a disadvantage of lower intensity. Indeed, the OTR intensity is few orders of magnitude smaller than the undulator radiation within the bandwidth of the CCD camera; hence we need to filter the undulator radiation in order to obtain a usable OTR image.

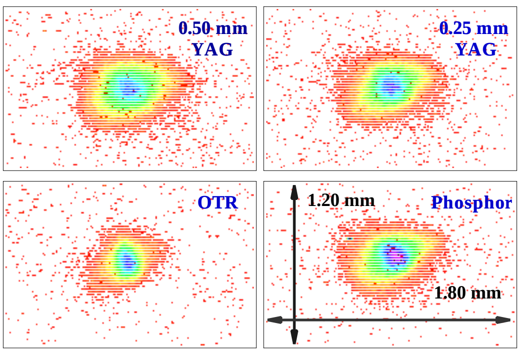

Figure 3: Images of the same electron beam, taken with 4 different methods. Comparison favours OTR as the diagnostics of the choice.

Fortunately, linear polarisation and harmonic spectral structure of the undulator emission allows to surpress it with respect to the radially polarised broad band OTR (Fig.2). At the present, the cold mirror periscope in the imaging optics provides 2 orders of magnitude noise reduction. In the future, if necessary, we plan to use polarising cubes to have even smaller fraction of the FEL light to enter the imaging optics. Another "side-effect" of the low intensity OTR implementation is that to get a clear performance the total resolution of the imaging system had to be changed from 4 µm/pixel as designed, up to 10 µm/pixel.

3. Alignment Laser System

Once the imaging system operates, the electron beam can be matched into the undulator. Yet, for the trajectory studies [5], it is necessary to have a reference line. A diode laser system is used to provide a reference line for the electron beam, and also to help with the alignment of optical components.

To this end we use a fiber–coupled diode laser at 632 nm, providing a single mode output, which we focus at the middle of the undulator, located 6 m away. Even though we are diffraction limited, we can achieve sub-millimeter spot sizes throughout the whole length of the undulator. CCD cameras on both sides of the undulator are used to monitor and periodically realign the reference laser beam line. This line is integrated into the interferometric undulator alignment system [6], to overlap the magnetic axis of the undulator. Once aligned, the laser is found to be stable within 20-30 microns from shot-to-shot. That is less than the typical horizontal jitter of the electron beam at the ATF, which is generally small due to the use of the energy collimator after the linac section [7].

The transport line for the FEL light consists of an imaging lens array to multiplex the radiation beam extracted from the different diagnostic ports [2]. As any system with the large number of optical elements, our optical transport line requires a narrow band coating (Ti:Sapphire); hence, an additional diode laser at 780 nm was added for optical alignment purposes. The two laser lines are collinear by virtue of a cold mirror.

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